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USE OF EARTH RESOURCES TECHNOLOGY SATELLITES (ERTS) TO DETERMINE TECTONIC CHARACTERISTICS NEAR LOW M_s-m_b EARTHQUAKES IN TIBET

R.R. BLANDFORD and J. GURSKI

Seismic Data Analysis Center

Teledyne Geotech, 314 Montgomery Street, Alexandria, Virginia 22314

2 DECEMBER 1975

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Examination of Earth Resources Technology Satellite (ERTS) photographs suggests intersecting faults within 10-20 kilometers of the NEIS epicenters of a cluster of low M_s-m_b events in Tibet. This suggests that the low M_s values may be due to some tectonic cause, for example dip slip thrust faults having high stress drop and small fault plane areas dipping about 45° which have been shown by Douglas to have low M_s-m_b. Therefore, unless the faults are steeply dipping, the low M_s values cannot be traced to attenuation of the Rayleigh waves due to great depths of the hypocenters.

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USE OF EARTH RESOURCES TECHNOLOGY SATELLITES (ERTS) TO DETERMINE TECTONIC CHARACTERISTICS NEAR LOW M_s-m_b EARTHQUAKES IN TIBET

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ABSTRACT

Examination of Earth Resources Technology Satellite (ERTS) photographs suggests intersecting faults within 10-20 kilometers of the NEIS epicenters of a cluster of low M_s-m_b events in Tibet. This suggests that the low M_s values may be due to some tectonic cause, for example dip slip thrust faults having high stress drop and small fault plane areas dipping about 45° which have been shown by Douglas to have low M_s-m_b. Therefore, unless the faults are steeply dipping the low M_s values cannot be traced to attenuation of the Rayleigh waves due to great depths of the hypocenters.

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INTRODUCTION

Der (1973) analyzed earthquakes from a small region surrounding 30°N, 95°E and found that some, but not all of them, fell near the explosion population on an M_s:m_b diagram as shown in Figure 1. Landers (1972) came to a similar conclusion with respect to one of these events.

In a follow-on study, Clark, Sweetser, and Der (1975) analyzed the short-period data from the low M_s-m_b events and concluded that first-motion and S/P amplitude ratios show that the events are earthquakes. Their conclusions with respect to depth of the events could not be definitive due to lack of adequate data, however they did point out that the high frequencies of the fundamental Rayleigh modes suggested that the depths could not be very great. Similar conclusions have been reached by Tatham et al. (1975).

In this report we study Earth Resources Satellite photographs of this area, together with published navigation charts, seismicity, tectonic, and geological maps to see what further light interpretation of the maps can throw on the subject.

Der, Z. A., 1973, M_s-m_b characteristics of earthquakes in the eastern Himalayan regions, Seismic Data Laboratory Report No. 296, Teledyne Geotech, Alexandria, Virginia.

Landers, T. E., 1972, Some interesting central Asian events on the M_s:m_b diagram, Geophys. J. R. Astr. Soc., 31, 329-339.

Clark, D., E. I. Sweetser, and Z. A. Der, 1975, Additional investigations of earthquakes with low M_s-m_b in Tibet-Himalaya Region, SDAC-TR-75-2, Teledyne Geotech, Alexandria, Virginia.

Tatham, R. H., D. W. Forsyth, and L. R. Sykes, 1975, Anomalous seismic events and the tectonics of the Himalayas (Abstract), EOS Transactions, American Geophysical Union, 56, 397.

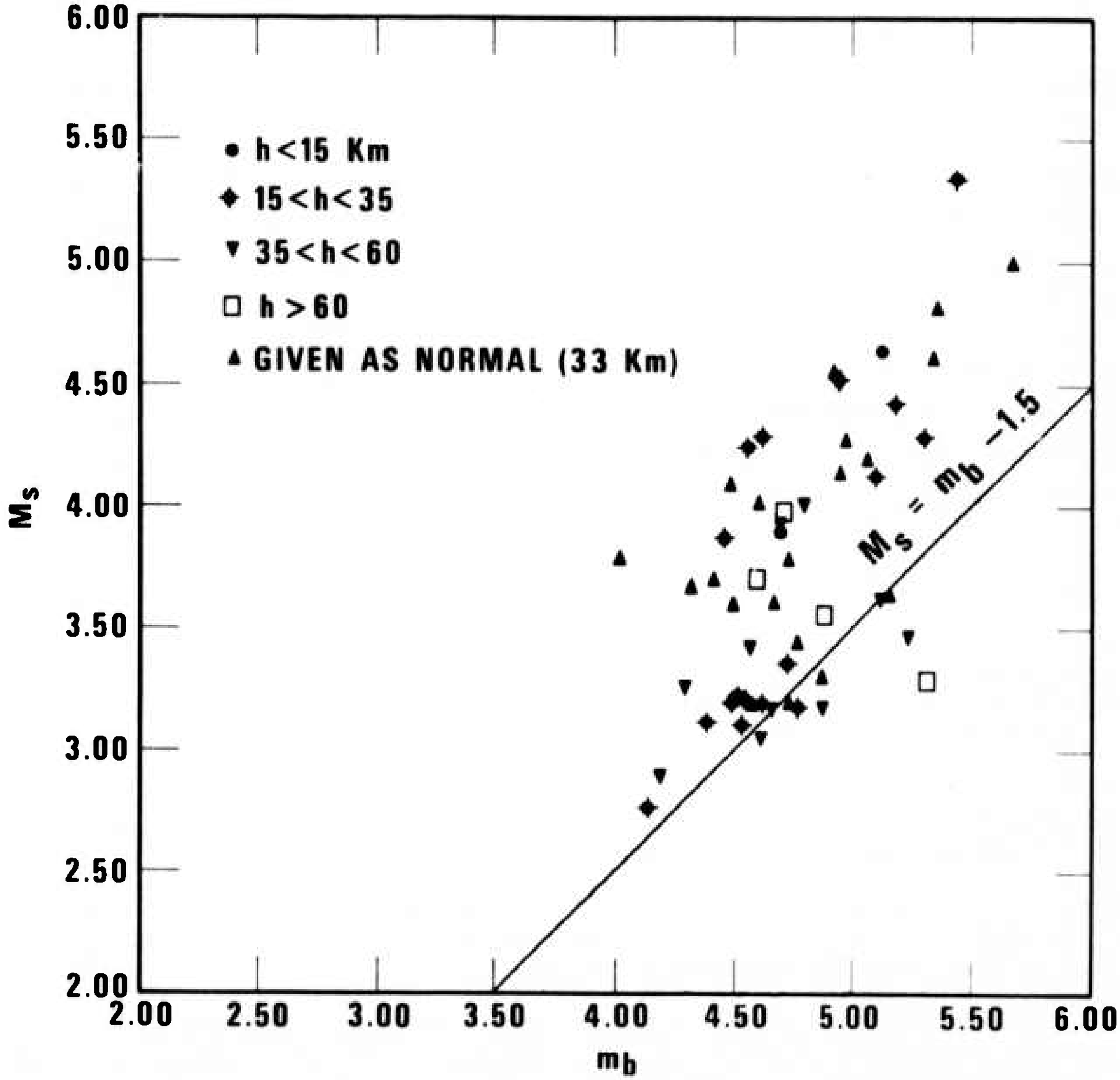

Figure 1. M_s vs m_b values corrected for mean station magnitude differences prior to averaging (from Der, 1973), events near $M_s = m_b - 1.5$ are predominantly near 30°N, 95°E.

ANALYSIS

Figure 2 from an NEIS seismicity map displays the seismicity of the region of interest. Events near the small cluster of events around 30°N, 95°E, especially a swarm in 1968, were in most cases found to have low $M_s - m_b$ by Der (1973).

Figure 3 is taken from a United Nations Geological Map of 1971 and shows a gradation from South to North of Precambrian granites to Mesozoic sediments. Several Mesozoic granite intrusive bodies are also indicated, and a fault is suggested as the boundary between the igneous and sedimentary formations.

Figure 4 from a map by Terman indicates a fault boundary of somewhat similar shape, but displaced to the south. Although there are differences in notation and substantial disagreement in detail, the fault still seems to be a boundary between older rocks to the South and younger ones to the North. Granitic Mesozoic intrusives are found to the North in this map also.

Similar remarks may be made with respect to the tectonic map by Yanshin (1966) of which Figure 5 is a tracing. This map does not agree well with either of the other two.

In Figure 6 we have superimposed the fault traces from Figures 3, 4, and 5, the seismicity of Table I, and lines indicating major structural elements (mostly valleys) from ERTS photographs. Figure 7 is one of these ERTS photographs. Table 2 gives the reference numbers for ERTS photos used in this report. The low $M_s - m_b$ events are located near the right hand center, as seen from the plastic overlay. Reference to Table I shows that most of the events at this point are anomalous. Event number 81 is the only event near

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United Nations Economic Commission for Asia and the Far East, 1971, (Second Edition), Geological map of Asia and the Far East.

Terman, M. J., Tectonic map of China and Mongolia, Geological Society of America, Boulder, Colorado.

Yanshin, A. L., 1966, Tectonic Map of Eurasia, Academy Nauk, U.S.S.R., Moscow.

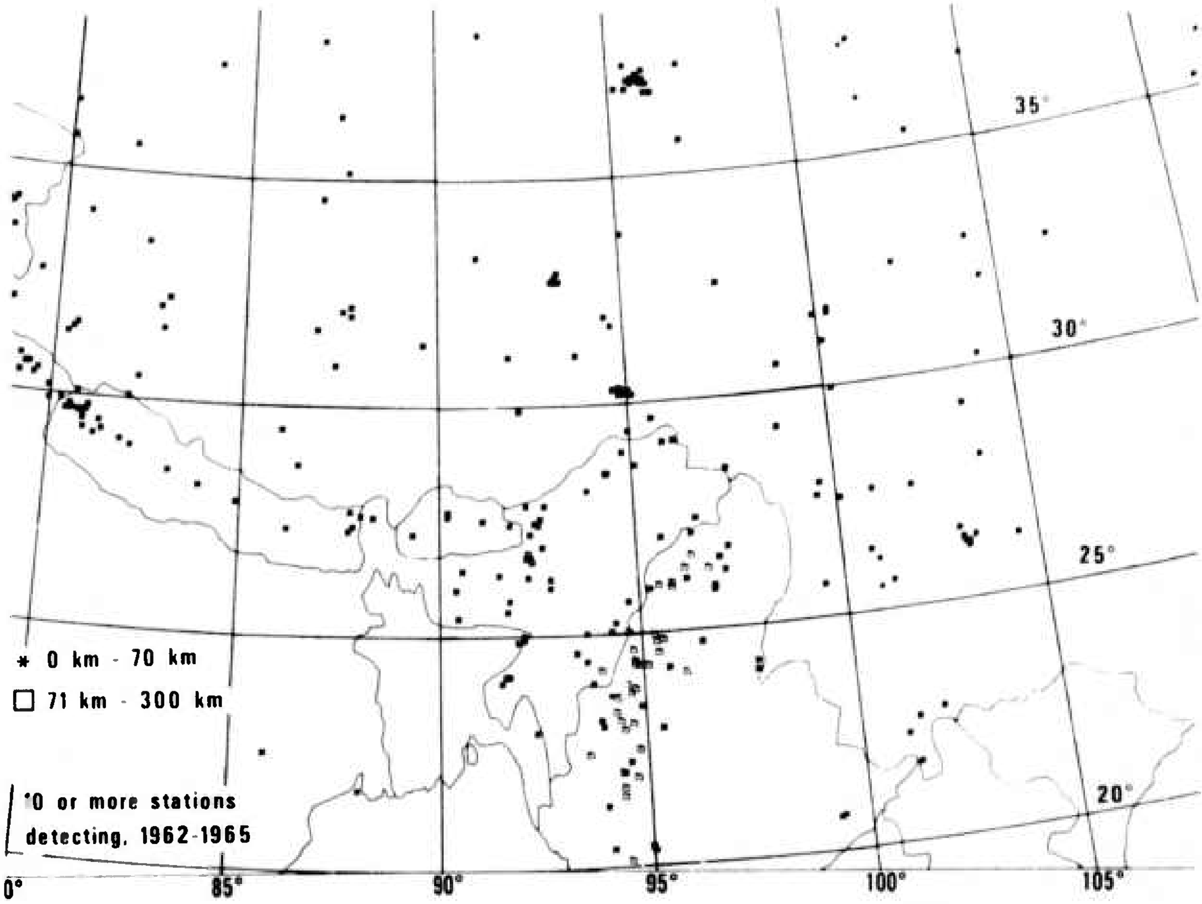


Figure 2. Extract from NEIS map of Seismicity of Central Asia.

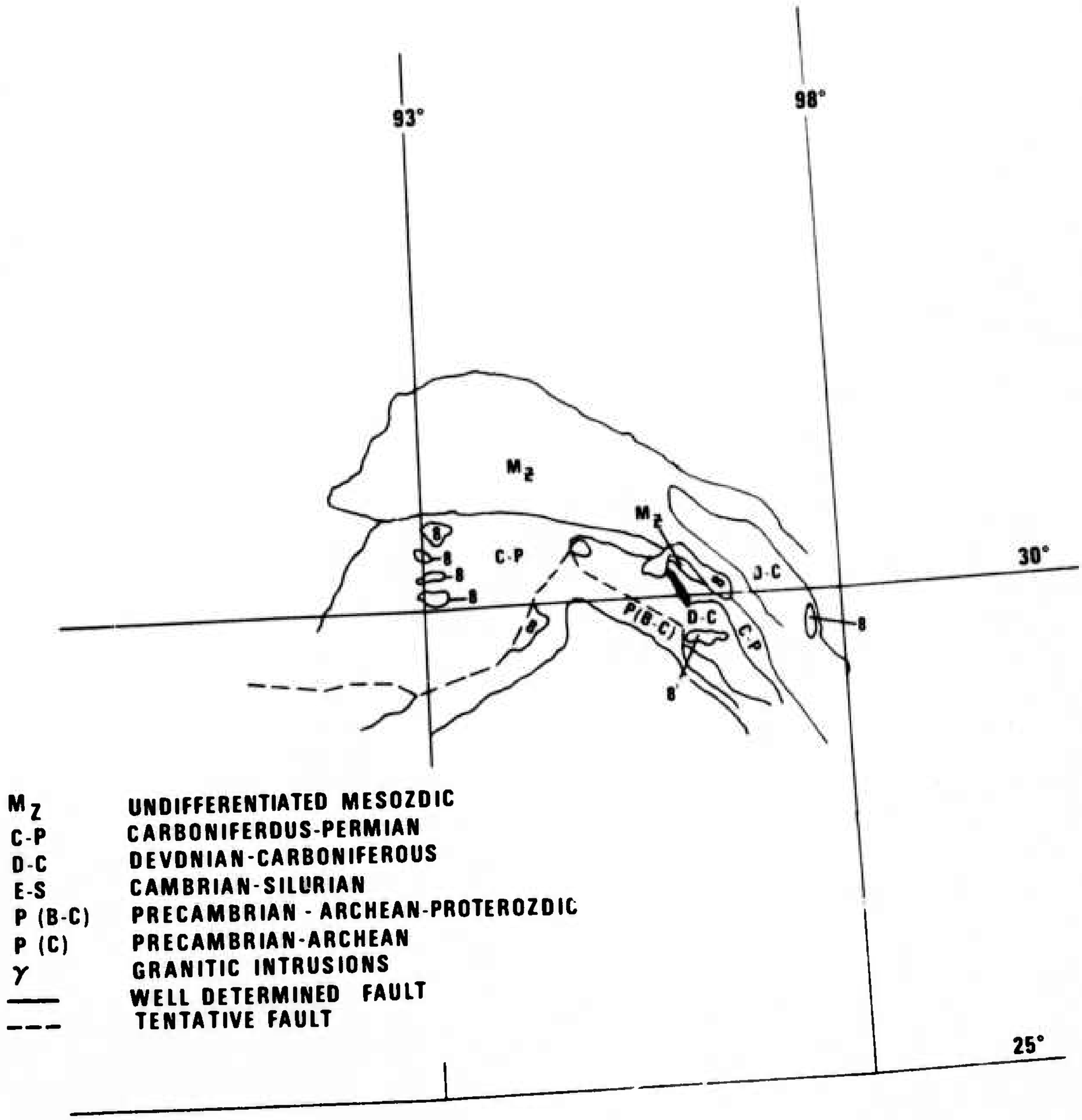


Figure 3. Extract from United Nations (1971) tectonic map (see reference).

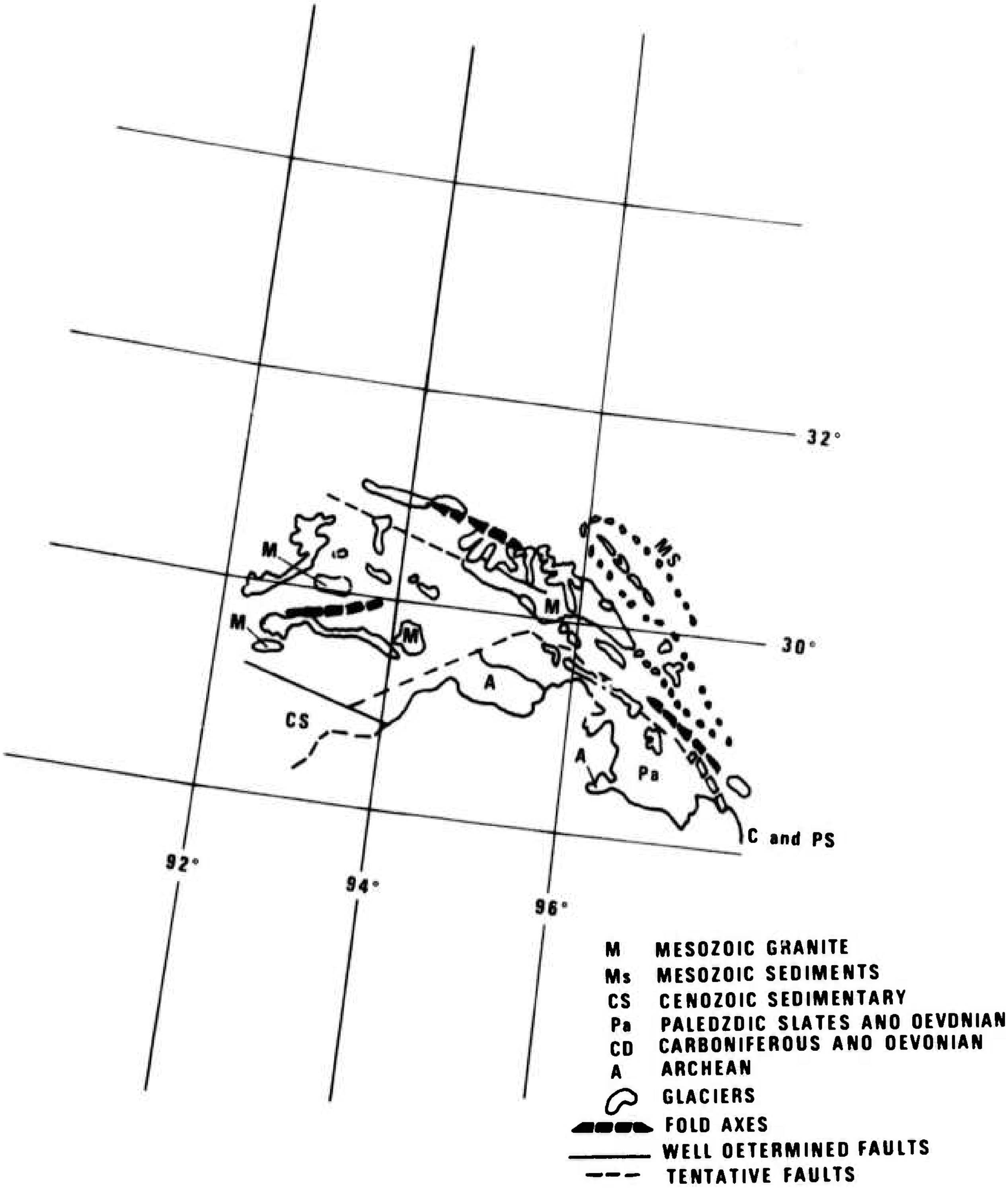
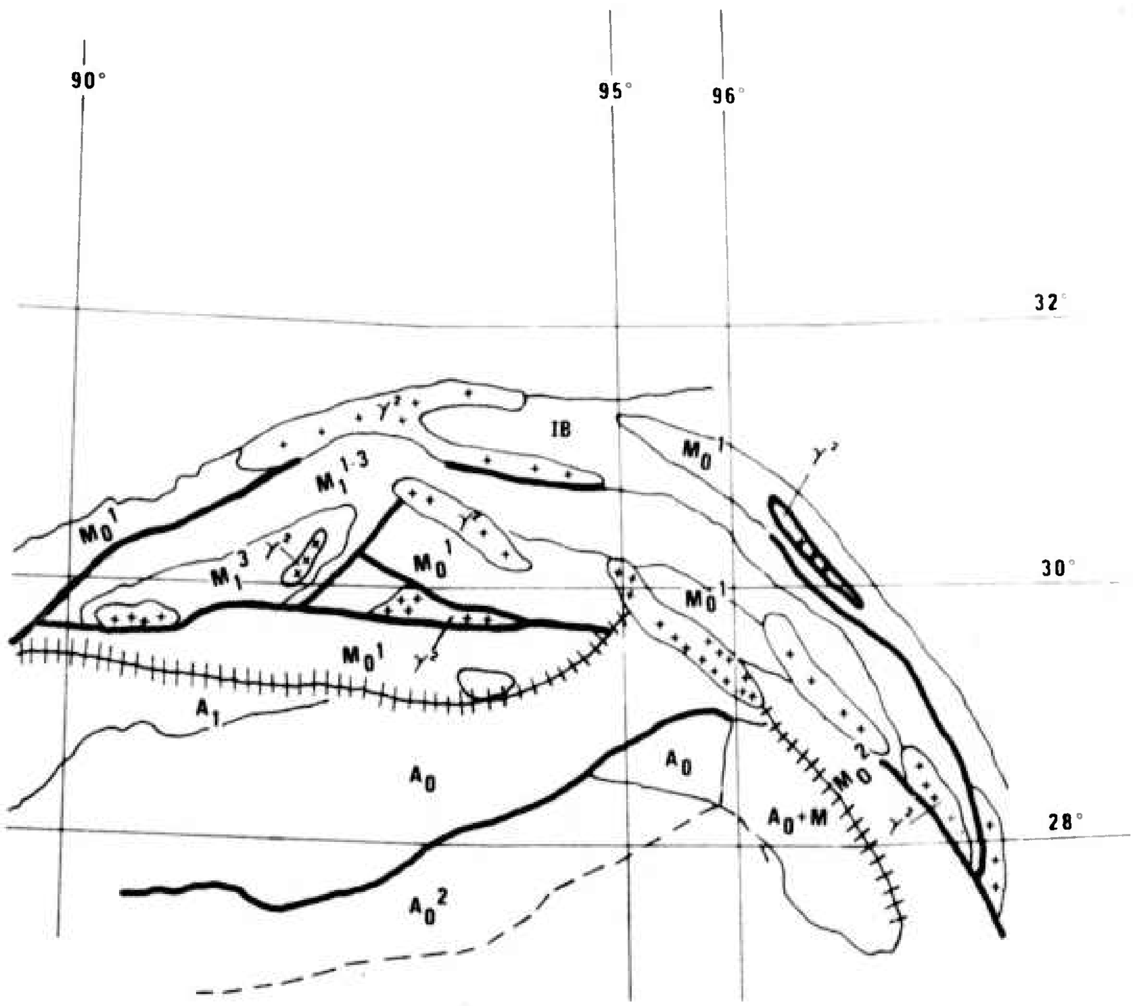


Figure 4. Extract from Tectonic map by Terman (see reference).



A_0 BUILT BY PRE-CAMBRIAN AND PALEOZOIC ROCKS (BASEMENT OUTCRDPS)

$A_0{}^2$ BUILT BY PALEOZOIC ROCKS

A1 LOWFR STRUCTURAL STAGE (LOWER ANO UPPER SUBSTAGES, UNDIVIOEO)

IB INTERIOR BASIN

M SUPERIMPOSEO METAMORPHISM OF VARIOUS AGES

$M_0{}^1$ BUILT BY PRE-RIPHEAN ROCKS (BASEMENT OUTCROP)

$M_0{}^2$ BUILT BY RIPHEAN ANO LOWER PALEOZDIC ROCKS (BASEMENT OUTCROP)

$M_1{}^{1\text{-}3}$ GEOSYNCLINAL FOLOEO COMPLEX (HOUSES MIOOLE AND UPPER SUBSTAGES, UNOIVIOED)

$M_1{}^3$ GEOSYNCLINAL FOLOEO COMPLEX (UPPER SUBSTAGE)

γ^2 ++++ LATE OROGENIC GRANITOIOS

┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼┼ MAIN DEEP FAULTS ———— TRACED FAULTS

Figure 5. Extract from Tectonic Map of Eurasia by Yanshin (1966) (see reference).

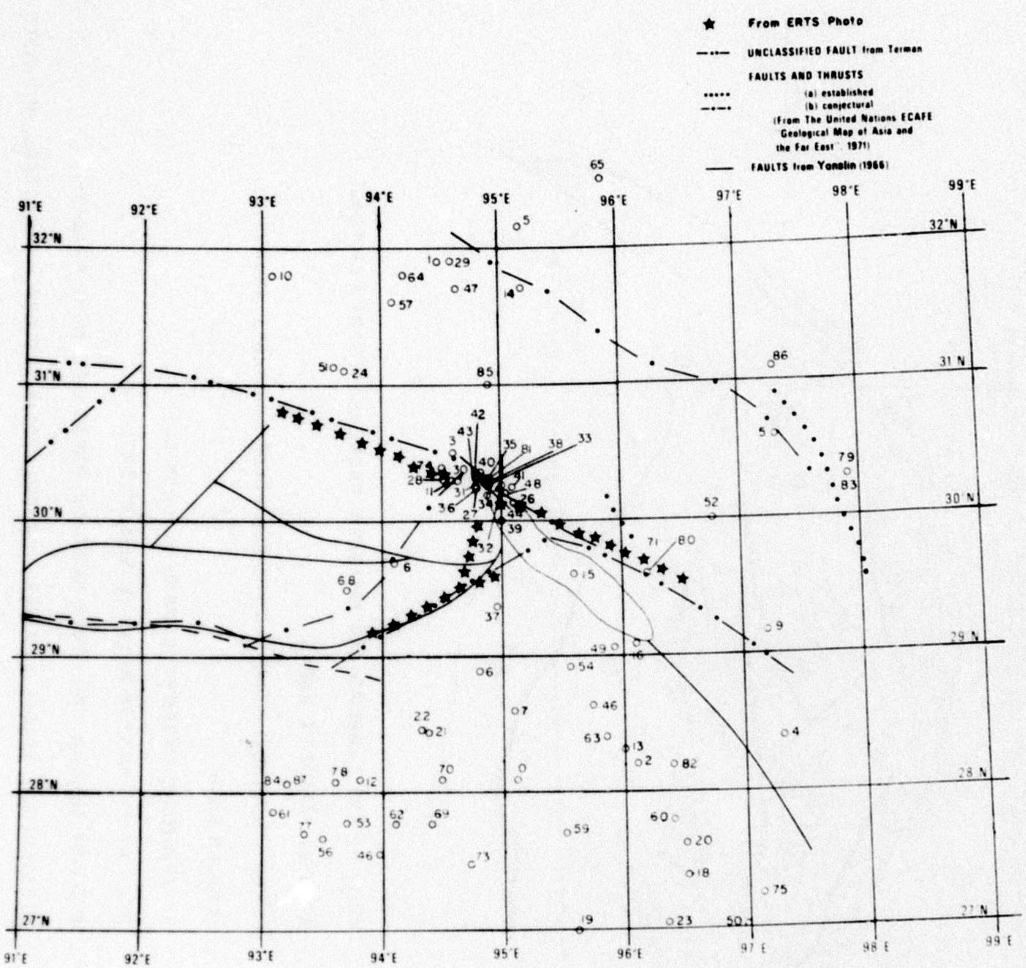


Figure 6. Superposition of selected features from Figures 3-5, ERTS photographs and seismicity from Table 1.

TABLE 1

NEIS SEISMICITY

1 January 1961 - June 1974

27°N-32.6°N, 93°E-98°E

Event #	Date	Origin Time	Location	Depth	NEIS m_b	Comments
1	620[illegible]20	23 10 39.5	31.900N 94.500E	31	0.00	
2	620325	13 38 56.3	28.200N 96.100E	25	0.00	
3	620910	22 47 07.6	30.500N 94.600E	33	0.00	
4	621018	02 00 02.7	28.400N 97.300E	60	0.00	
5	621019	09 17 12.4	30.600N 97.300E	29	0.00	
6	630602	07 07 57.3	28.900N 94.800E	53	0.00	
7	631008	02 51 06.0	28.600N 95.100E	24	0.00	
8	631116	11 39 37.8	28.100N 95.100E	37	5.40	
9	640127	05 29 27.3	29.200N 97.200E	33	4.70	
10	640610	17 55 42.9	31.800N 93.100E	71	4.90	
11	641006	02 54 32.7	30.300N 94.600E	33	5.00	
12	641021	23 09 18.8	28.100N 93.800E	37	4.50	
13	650430	07 13 23.1	28.300N 96.000E	33	5.90	
14	650604	15 56 56.4	31.700N 95.200E	33	4.40	
15	650615	07 59 19.4	29.600N 95.600E	30	5.00	
16	651006	08 03 05.1	29.100N 96.100E	41	5.60	
17	660314	04 42 50.4	32.500N 97.500E	33	5.40	
18	660527	14 35 04.9	27.400N 96.500E	44	4.80	Off Map
19	660911*	15 55 19.4	27.000N 95.600E	27	4.70	
20	670210	21 00 13.5	27.628N 96.494E	33N	4.80	
21	670311	16 56 50.2	28.434N 94.367E	12	4.70	
22	670314	06 58 03.2	28.458N 94.318E	12	5.30	
23	670316	12 13 24.1	27.055N 96.341E	24	5.80	
24	670815	09 21 02.3	31.100N 93.700E	33	4.80	
25	670922	20 09 13.3	31.900N 94.600E	33	5.70	
26	680628*	20 34 55.3	30.139N 95.102E	44	0.00	
27	680630*	05 04 10.0	30.244N 94.809E	42	4.80	
28	680701*	03 11 10.0	30.310N 94.539E	28	4.80	
29	680704*	06 45 58.0	30.251N 94.878E	33N	4.30	
30	680713*	06 05 54.2	30.300N 94.636E	33N	4.70	
31	680714*	18 12 41.0	30.252N 94.792E	22	5.00	
32	680715	05 09 05.9	30.266N 95.002E	22	4.90	
33	680716*	22 23 07.0	30.272N 94.804E	40	4.80	
34	680719*	18 48 59.0	30.189N 94.879E	33N	4.80	
35	680723*	20 51 47.9	30.285N 94.863E	30	4.90	
36	680725*	03 34 13.0	30.244N 94.806E	33N	4.90	
37	680726*	12 44 03.0	29.371N 94.951E	33N	4.80	
38	680823*	12 01 16.5	30.281N 94.852E	33N	4.90	
39	680824	14 26 07.4	30.012N 95.062E	56	4.80	
40	680825*	17 55 05.3	30.351N 94.825E	19	4.60	

Table 1 (Continued)

Event #	Date	Origin Time	Location	Depth	NEIS m_b	Comments
41	680829*	19 51 24.6	30.243N 95.100E	33N	5.00	
42	680901*	05 59 26.6	30.321N 94.801E	20	5.00	
43	680903*	17 45 54.1	30.180N 94.804E	53	4.90	
44	680911	03 07 32.0	30.252N 94.886E	38	4.30	
45	680916	17 02 40.2	28.626N 95.744E	60	4.70	
46	690207	09 25 38.8	27.581N 93.967E	33N	0.00	
47	690614	03 28 29.6	31.697N 94.649E	33N	5.30	
48	690815*	07 15 37.0	30.207N 95.037E	33N	5.20	
49	691022	02 33 21.2	29.060N 94.826E	33	4.60	
50	700119	12 57 28.4	27.032N 94.961E	45	4.60	
51	700208	19 07 30.0	31.129N 93.511E	33N	4.50	
52	700214	05 25 07.1	30.010N 96.786E	14	0.00	
53	700219	07 10 01.8	27.396N 93.990E	18	5.50	Off Map
54	700624	00 43 01.9	28.933N 95.568E	33N	4.80	
55	710604	14 10 46.0	32.152N 95.177E	33	5.00	
56	710817	18 48 56.0	27.700N 93.500E	33C	4.30	
57	710819	13 14 30.0	31.600N 94.100E	33C	4.60	
58	711112	23 58 39.0	27.800N 93.700E	33C	4.40	
59	720316	12 00 08.0	27.700N 95.500E	33C	3.60	
60	720322	16 15 38.0	27.800N 96.400E	33C	3.70	
61	720525	02 17 13.0	27.900N 93.100E	33C	3.70	
62	720525	02 21 40.0	27.800N 94.100E	33C	4.00	
63	720602	20 32 55.3	28.394N 95.856E	33	4.30	
64	720617	21 41 10.0	31.800N 94.200E	33C	3.90	
65	720716	02 20 23.6	32.496N 95.888E	33	5.20	
66	720716	03 39 59.8	32.559N 95.780E	33	4.70	Off Map
67	720810	21 06 40.1	32.421N 93.474E	33	5.20	Off Map
68	720917	13 43 32.0	29.500N 93.700E	33C	3.70	
69	721007	03 16 52.0	27.800N 94.400E	33C	3.80	
70	721101	21 54 22.0	28.100N 94.500E	33G	5.30	
71	721207	04 14 36.0	29.600N 96.200E	33C	3.80	
72	730423	16 18 42.0	27.500N 93.400E	33C	3.60	Off Map
73	730529	08 31 39.0	27.500N 94.700E	33C	3.50	
74	730723	22 17 10.0	30.400N 94.500E	33C	3.80	
75	730731	21 06 14.9	27.256N 97.092E	33	4.80	
76	730929	21 10 53.0	29.700N 94.100E	33C	3.80	
77	731009	04 01 47.4	27.751N 93.350E	33	4.80	
78	731013	14 51 16.0	28.100N 93.600E	33C	3.70	
79	731206	02 40 54.0	30.300N 97.900E	33C	3.80	
80	731213	23 26 13.0	29.600N 96.200E	33C	4.00	
81	731221*	02 08 47.5	30.292N 94.870E	33	4.80	
82	740116	15 18 32.0	28.200N 96.400E	33C	3.80	
83	740213	02 26 42.0	30.300N 97.900E	33C	3.90	
84	740217	06 08 49.0	28.100N 93.200E	33C	3.70	
85	740320	10 55 16.0	31.000N 94.900E	33C	3.70	
86	740401	00 43 43.0	31.100N 94.300E	33C	3.80	
87	740611	19 02 56.0	28.100N 93.200E	33C	3.40	

*Selected for study as anomalous by Der (1975) and having $M_s - m_b < -1.0$, with the exception of event 81, which occurred recently and was also anomalous.

Figure 7. ERTS photo of area near 30°N, 95°E with seismicity and tectonic overlay.

(Located at back of this report)

TABLE 2

Reference Numbers for Infra-red Band 7 ERTS Negatives Used for Figures 5 and 6.

1535-03441

*1535-03443

1535-03450

1480-03392

1480-03395

1480-03401

1461-03340

1461-03343

1461-03345

*Only this negative used for Figure 6.

30°N, 95°E to occur through June, 1974 after publication of Report 296 by Der (1973). This event also has low values for M_s-m_b. Operational navigation charts of the United States Department of Commerce show only trails and un-named small settlements within 150 km of the earthquake cluster. The nearest large town is Dibrugrh 250 km south in East Inda. The lines of small stars in Figures 6 and 7 indicate regions on the map for which we could find supporting evidence in the photographs for the faults illustrated in Figures 3, 4, and 5. The long northwest-southeast trending feature seems far too straight to be anything but a fault, and several minor lineations are visible along it. The shorter northeast trending features are prominent in the photographs, and seem to be the best possible match to the corresponding faults in Figures 3, 4, and 5. However, no clear small lineations were visible.

We note in Figure 7 that to an accuracy of 10-20 km the cluster of seismicity lies on the long northwest-southeast fault and at its intersection with the projected northeast trending fault.

Fault-plane solution work by several authors has been summarized by Tatham et al. (1975) in Figure 8. There are no events near 30°N, 95°E, but there seem to be faults of every type in the general region. However, thrust faults predominate. Even for a fault dip of 40°-60°, if the epicenter is within 10-20 km of the surface trace, it must be less than 20-40 km deep. Thus it is plausible to believe that if these earthquakes are near the surface expression of a fault, then they cannot be very deep. Of course, it is always possible that biased mislocations may accidently have displaced the epicenters onto the surface expression of the fault or that the fault is vertical and the events deep. However, the most economical explanation is that there is no bias, that the faults are not vertical, and that the events are shallow. The existing seismic data are inadequate to determine a fault plane for these events.

U. S. Department of Commerce, Operational Navigation Charts, National Oceanic and Atmospheric Administration, National Ocean Survey (C-44), Riverdale, Maryland.

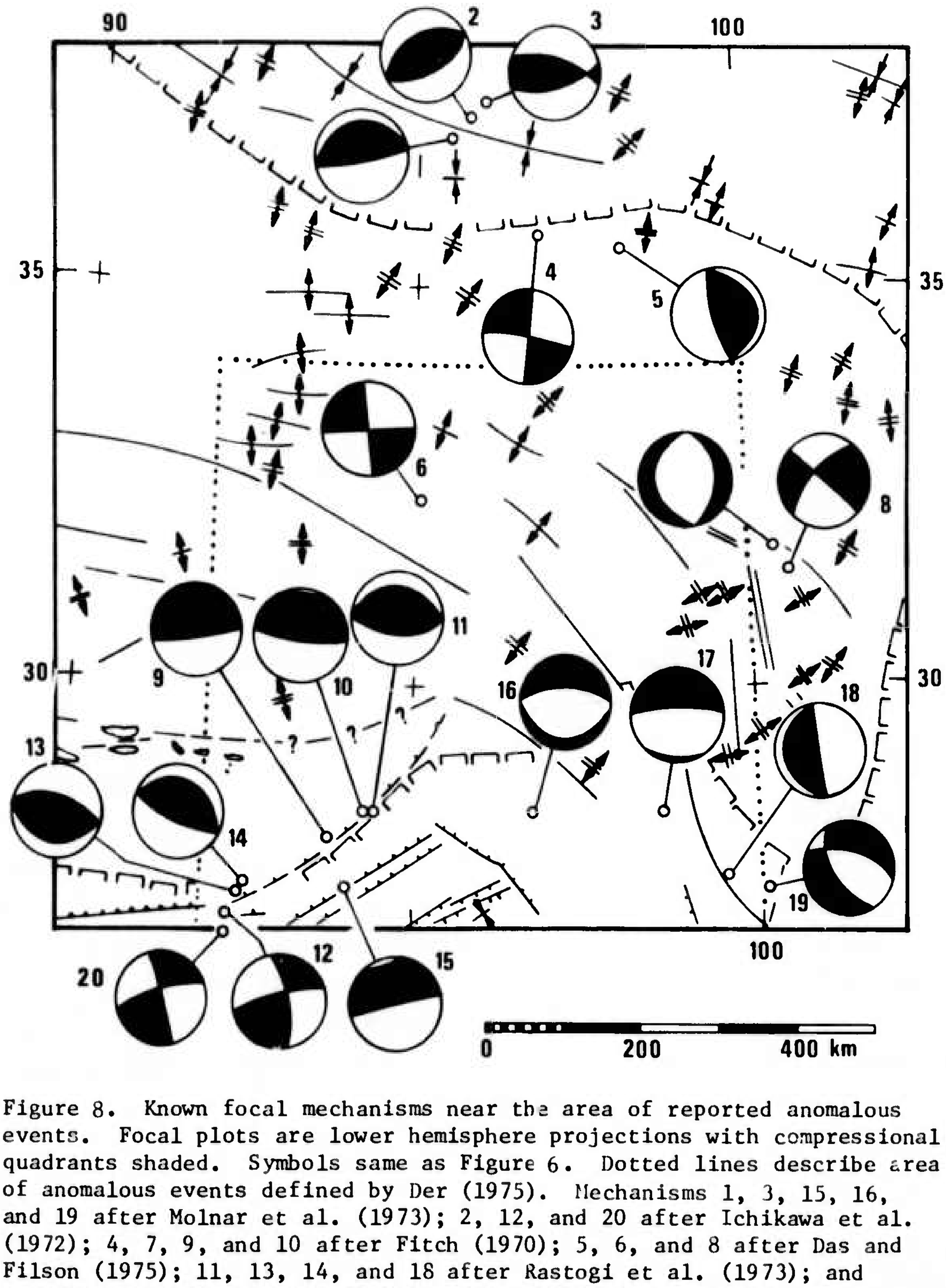


Figure 8. Known focal mechanisms near the area of reported anomalous events. Focal plots are lower hemisphere projections with compressional quadrants shaded. Symbols same as Figure 6. Dotted lines describe area of anomalous events defined by Der (1975). Mechanisms 1, 3, 15, 16, and 19 after Molnar et al. (1973); 2, 12, and 20 after Ichikawa et al. (1972); 4, 7, 9, and 10 after Fitch (1970); 5, 6, and 8 after Das and Filson (1975); 11, 13, 14, and 18 after Rastogi et al. (1973); and mechanism 17 after Tandon (1954). From Tatham et al. (1975).

The complexity of the fault patterns also suggests that well-defined slip zones to accomodate convergence have not yet been established and that high stresses could develop. With high stresses, even an earthquake with a small fault plane area could have reasonably high values for M_s and m_b. But the work of Douglas et al. (1973) and of Blandford (1975) suggests that small "point" earthquakes with 45° dip-slip mechanism are precisely those which fall in the explosion population on an $M_s:m_b$ plot. Blandford and Clark (1975) conclude that many events near the Pacific shore of Kamchatka, which are also 45° dip-slip according to work by Veith (1974), fall on an $M_s:m_b$ plot very near the events of 30°N, 95°E.

Taken together, all of the above is consistent with the hypothesis that all "anomalous" events are small 45° dip-slip events. If so, the principal route to identification would have to be via short-period discriminants for events which are not too shallow (see Shumway and Blandford, 1974), or via the ratio of shear to Rayleigh or shear to other body phases, von Seggern (1972) and Blandford and Clark (1974).

Douglas, A. J. A. Hudson, and C. Blamey, 1973, A quantitative evaluation of seismic signals at teleseismic distances--III computed P and Rayleigh wave seismograms, Geo. J. R. Astr. Soc., 28, 385-410.

Blandford, R., 1975, A source theory for complex earthquakes, Bull. Seism. Soc. Am., 65, .

Blandford, R. and D. Clark, 1975, Variability of seismic waveforms at LASA from small subregions of Kamchatka, SDAC-TR-75-12, Teledyne Geotech, Alexandria, Virginia.

Veith, C., 1974, The relation of island arc seismicity to plate tectonics, Ph.D. Thesis, Southern Methodist University.

Shumway, R. and R. Blandford, 1974, An examination of some new and classical short period discriminants, SDAC-TR-74-10, Teledyne Geotech, Alexandria, Virginia.

von Seggern, D., 1972, Seismic shear waves as a discriminant between earthquakes and underground nuclear explosions, Seismic Data Laboratory Report No. 295, Teledyne Geotech, Alexandria, Virginia.

Blandford, R. and D. Clark, 1974, Detection of long-period S from earthquakes and explosions with application to positive and negative discrimination of earthquakes and underground nuclear explosions, SDAC-TR-74-15, Teledyne Geotech, Alexandria, Virginia.

RECOMMENDATIONS

More might be learned of the fault structures in this area from summer false-color imagery. Examination of false-color pictures corresponding to Figure 7 was not helpful because of the interfering effects of the snow cover.

With considerably greater level of effort than was expended on this report, it would be possible to go back to the original data tapes from the ERTS satellites and construct higher resolution photographs with enhanced contrast in the shadows and highlights.

If newer, higher resolution data becomes available, they should be examined.

A comprehensive project to clarify the geology of this site seems warranted, considering the disagreement among published maps, and between those maps and the ERTS photographs. It would seem that both high resolution photography and field-trips would be needed. Perhaps this would be a worthwhile project for cooperation with foreign governments.

When new data becomes available from the VELA Network, including the Seismic Research Observatory stations, it may be possible to determine long-period body wave fault-plane solutions for very weak events from this area, and to see if the mechanisms for low M_s-m_b events are indeed 45° dip-slip. Also, more accurate estimation of depth from short-period P detections may be possible.

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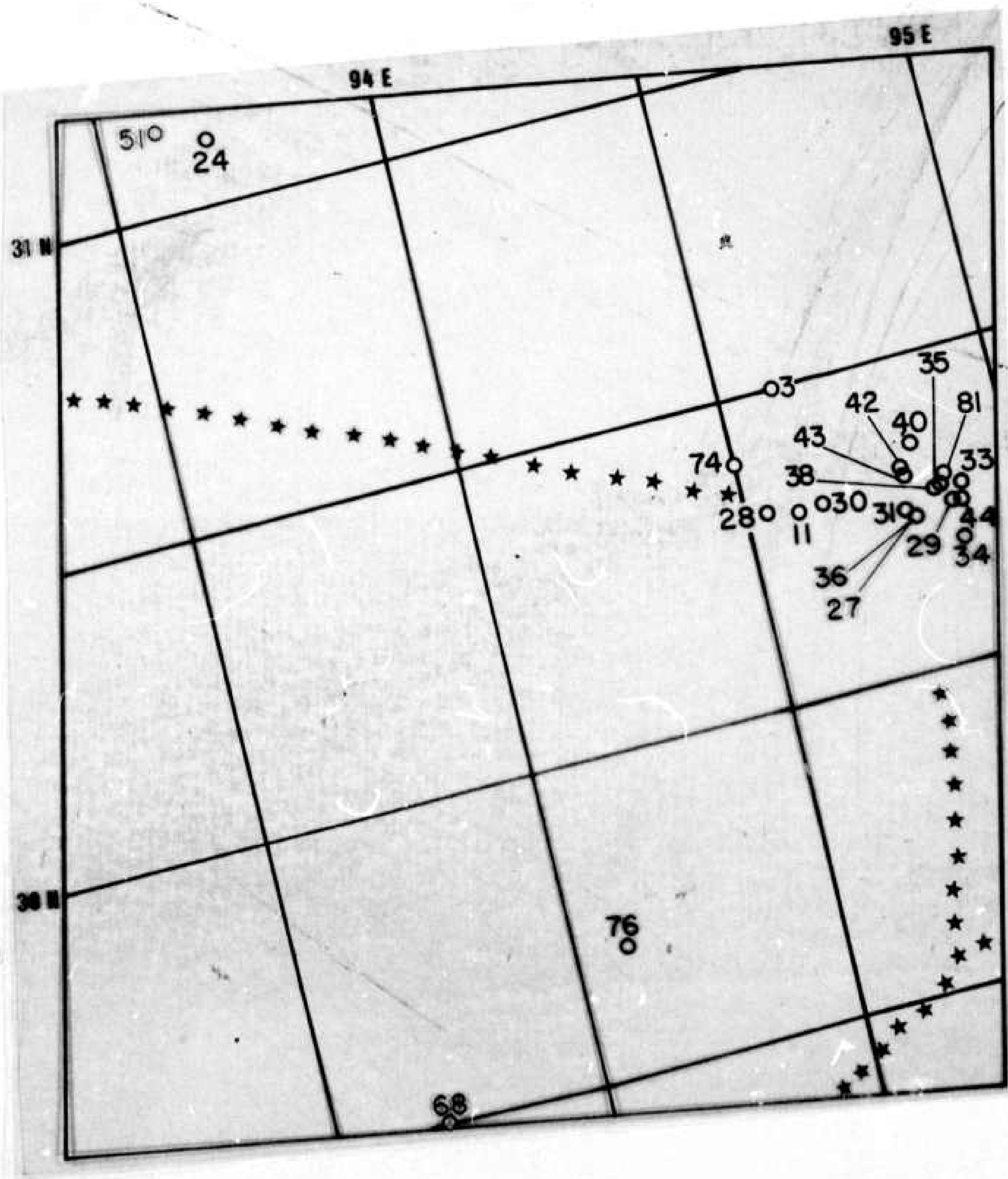

94 E
95 E
31 N
30 N
51
24
3
35
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81
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74
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68

Figure 7. ERTS photo of area near 30°N, 95°E with seismicity and tecconic overlay.

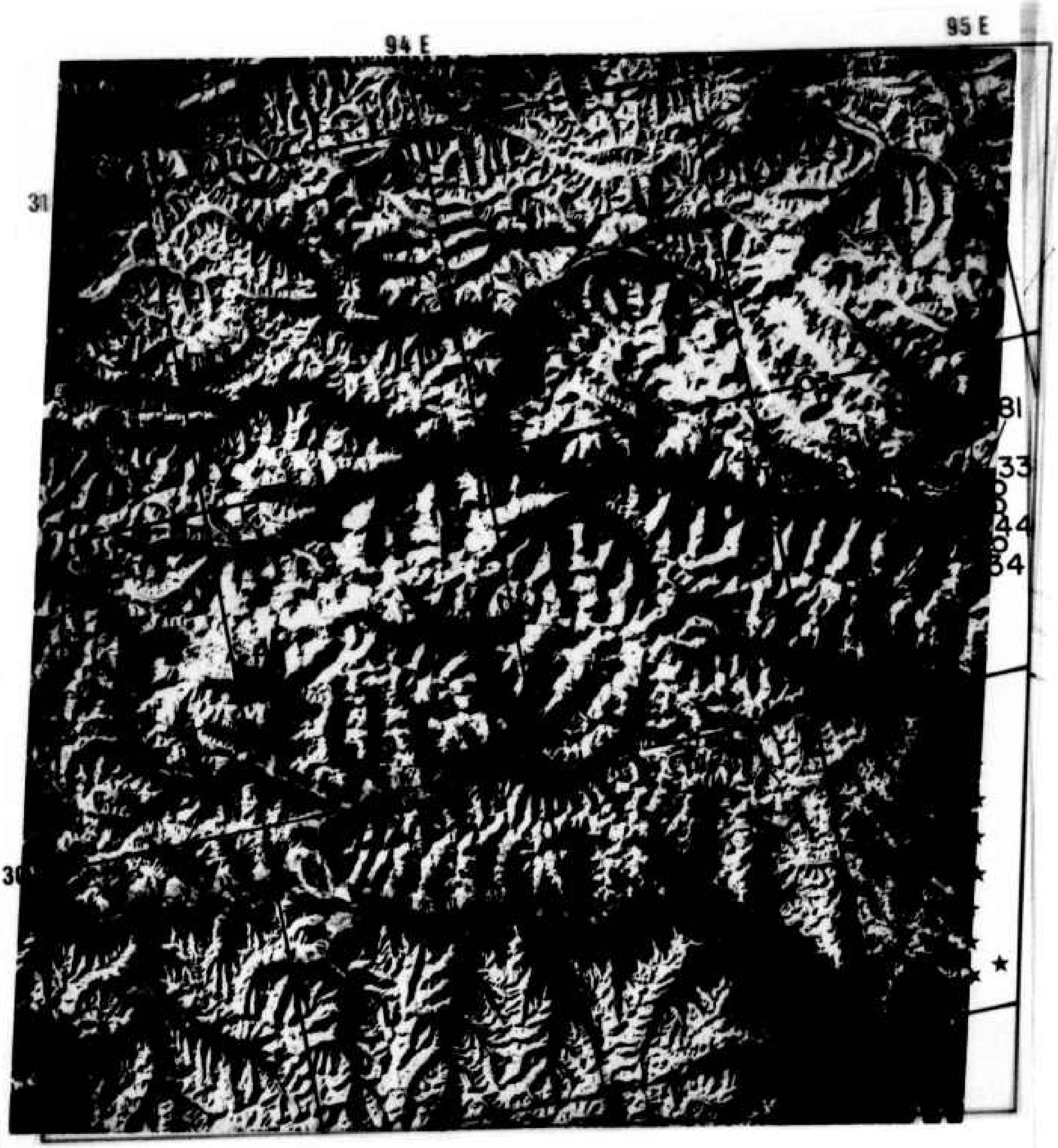

Figure 7. ERTS photo of area near 30°N, 95°E with seismicity and tectonic overlay.